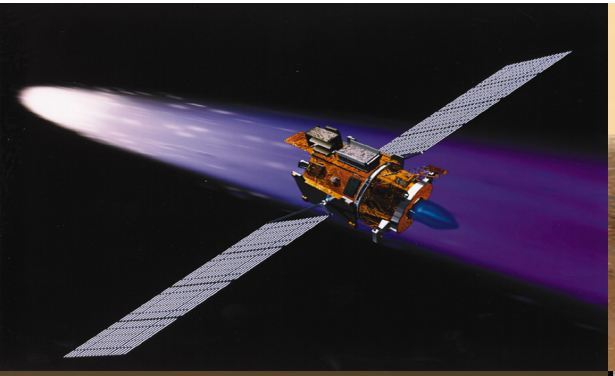
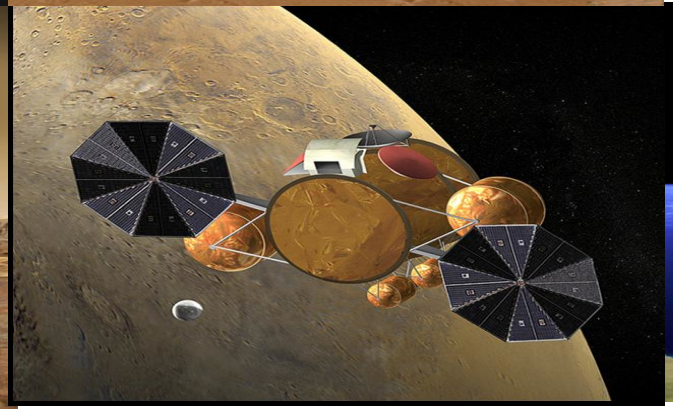
Spacecraft Bus and Platform Technology Development under the NASA ISPT Program











David Anderson, Michelle Munk, Eric Pencil, John Dankanich, Lou Glaab, and Todd Peterson

JANNAF, 6th Spacecraft Propulsion Meeting, Colorado Springs, CO
May 2, 2013

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NASA's In-Space Propulsion Technology (ISPT) Program

NASA's ISPT Program develops critical propulsion, entry vehicle, and other spacecraft and platform subsystem technologies to enable or significantly enhance future planetary science missions.

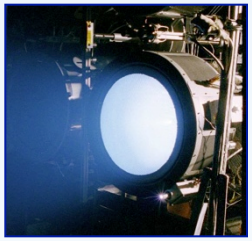
- *The current ISPT focus is TRL 3-6+ product development that:*
 1. *Enable access to more challenging and interesting science destinations*
 2. *Or, benefit future robotic science missions by significantly reducing travel times to distant bodies, increasing scientific payload capability, or reducing mission cost and risk.*

Propulsion System Technologies

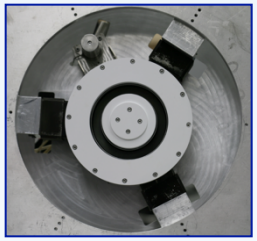
AMBR High-Temp Rocket Engine



7 kW NEXT Ion Propulsion System

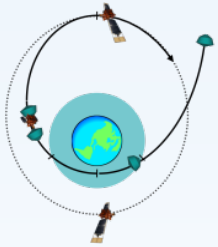


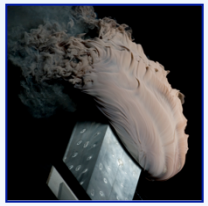
4 kW HIVHAC Thruster & Hall Propulsion System



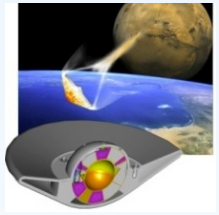
Entry Vehicle Technologies

Aerocapture





Multi-Mission Earth Entry Vehicle



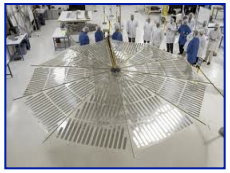
Spacecraft Bus & Sample Return Technologies

Mars Ascent Vehicle



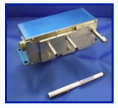


PV Array Systems for planetary missions



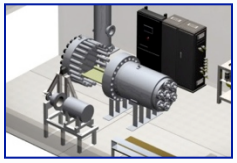
Spacecraft Bus Components





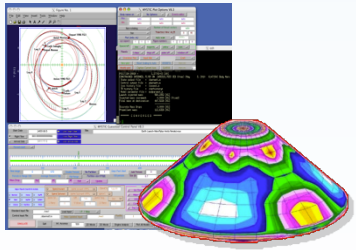


Extreme Environments

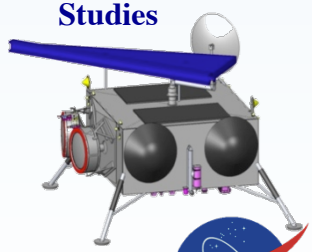


Systems & Mission Studies

Mission Analysis Tools



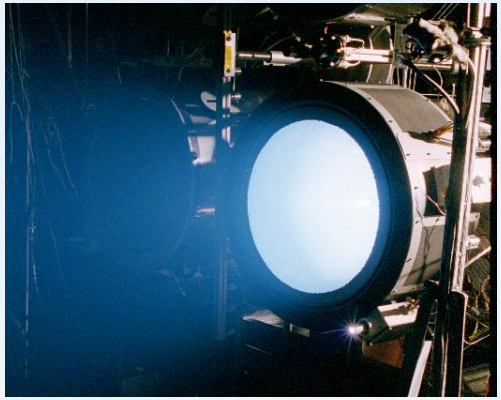
Mission and System Studies



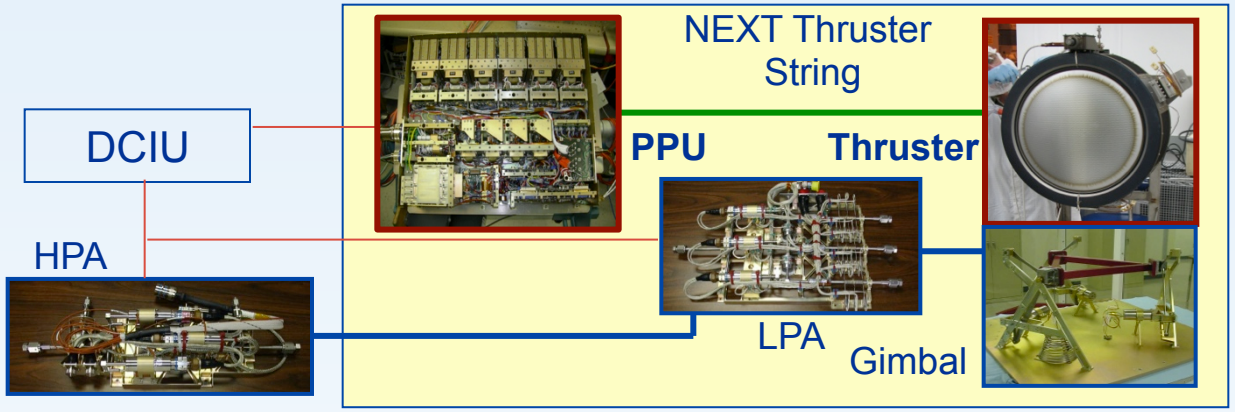
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NEXT: Expanding SEP Applications For SMD Missions

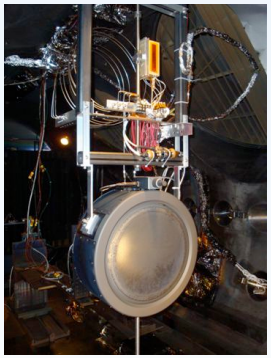
***Objective:** Improve the performance and life of gridded ion engines to reduce user costs and enhance/enable a broad range of NASA SMD missions*



NEXT PM ion thruster operation at NASA GRC



* Rated Capability Goal 300Kg → Design/Qualification Goal (1.5x Rated) 450Kg
Projected Life Limit >800Kg → Potential Rated Capability >530Kg

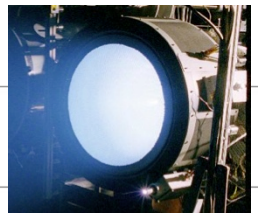


NEXT Thruster has exceeded all goals!

- Single-String System Integration Test: **Complete**
- Multi-String System Integration Test: **Complete**
- Thruster Life Test: 450Kg throughput goal **Surpassed**
- *As of April 11, 2013, the LDT has achieved >840 kg xenon throughput, >47,100 hours of operation and >32.4 Mn-sec of total impulse*
- Life Test voluntarily stopped 4/1/13 and transitioned to post-test inspections of thruster
- Unprecedented diagnostics used for NEXT thruster performance characterization and spacecraft interaction effects testing ongoing at TAC

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NEXT Mission Benefits & Applicability



Goals

Current throughput projection >870±75 kg

Current NEXT Qualification Level (554kg)

Original NEXT Design Goal (300 kg)

NEXT LDT

NSTAR ELT

NSTAR DS-1

Propellant Throughput, kg

Total Elasped Time, kh

0 100 200 300 400 500 600 700 800 900

0 5 10 15 20 25 30 35 40 45 50

Representative Mission Concept Throughput Requirements

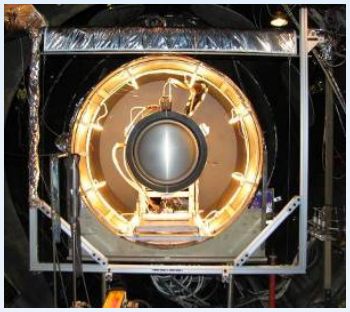
- 522 kg – Multi-asteroid Rendezvous
- 503 kg – Ceres SR
- 499 kg – Mars Orbiter
- 450 kg – NWO
- 442 kg – Main-belt SR
- 426 kg – Uranus orbiter
- 418 kg – Bepi-Columbo
- 405 kg – CSSR
- 360 kg – Multi-asteroid SR
- 338 kg – Multi-asteroid Rendezvous
- 300.8 kg - Comet SR Qualification
- 275 kg – TSSM
- 263.5 kg – Vesta-Ceres
- 262.7 kg – Neptune DSDRM
- 250 kg – Titan Lander
- 246 kg – Comet Rendezvous
- 242.3 kg – Saturn DSDRM
- 200 kg – EZE
- 176.3 kg – NEAR Mission

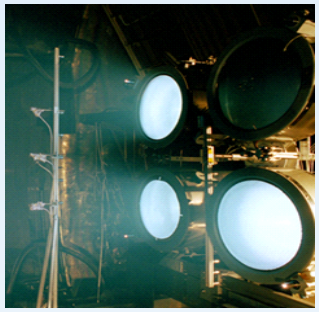
Projected Qualification Level:	>580kg
Equivalent Qualification Level:	554 kg
Original NEXT Design Goal :	300 kg

Projected Throughput:	>870.0 kg
NEXT LDT Demonstrated (as of 3/22/2013):	**831.1 kg**
Original NEXT Qualification Requirement:	450.0 kg

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NEXT Mission Benefits & Applicability





CHARACTERISTIC	NSTAR (SOA)	NEXT	Improve-ment	NEXT BENEFIT
Max. Thruster Power (kW)	2.3	6.9	3x	Enables high power missions with fewer thruster strings
Max. Thrust (mN)	91	236	2.6x	
Throttling Range (Max. / Min. Thrust)	4.9	13.8	3x	Allows use over broader range of distances from Sun
Max. Specific Impulse (sec)	3120	4190	32%	Reduces propellant mass, enabling more payload and/or lighter spacecraft
Total Impulse (10^6 N-sec)	4.6	>30	>6x	Enables low power, high ΔV Discovery-class missions with a single thruster
Propellant Throughput (kg)	150	>550	>3x	

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Solar Electric Propulsion Mission Analysis

HIVHAC and BPT-4000 performance Comparison

Performance Characteristics of HIVHAC vs. SOA Hall (BPT-4000).

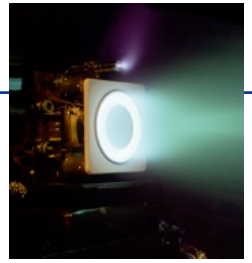
Characteristic	BPT-4000	HIVHAC
Thruster Power Range, kW	0.3-4.5	0.3-3.9
Throttle Ratio	15:1	12:1
Operating Voltage, V	150-400	200-700
Specific Impulse, sec	710-2100	860-2700
Thrust, mN	22-260	20-207
Efficiency	0.25-0.58	0.32-0.62
Propellant Throughput, kg	450	>300

BPT-4000

NEA Rendezvous

NEA Sample Return

Mars Sample Return



HIVHAC

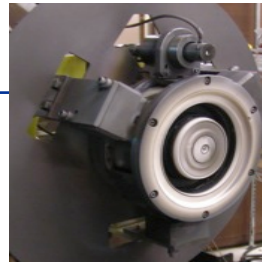
NEA Rendezvous

NEA Sample Return

Multi-Main Belt Rendezvous

Comet Rendezvous

Dawn



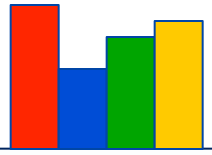
Development to go

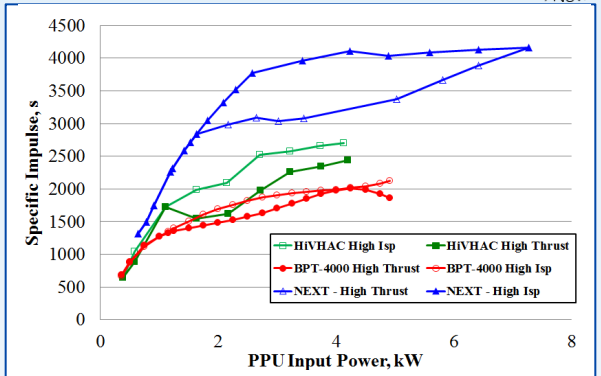
Nth User Cost

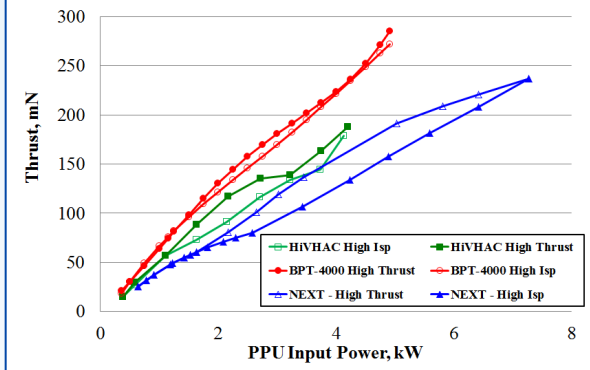
Capability

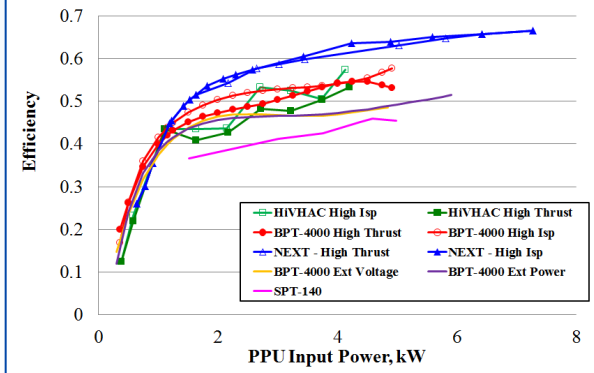
Science Return









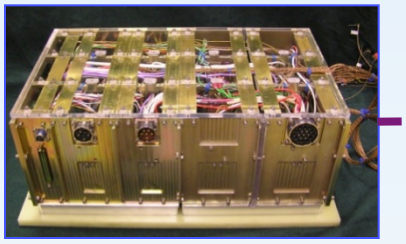


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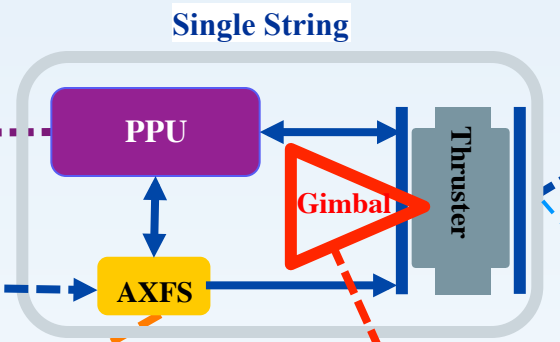
High Voltage Hall Accelerator (HIVHAC)

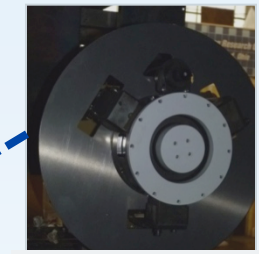
Electric Propulsion for low cost Discovery-class and Sample Return Missions

Objective: *Develop key components of a HIVHAC Hall propulsion system (thruster, PPU/DCIU, feed system) to TRL 6 to enable/enhance new SMD Discovery missions; expand operational capability to close near-earth mission applications*



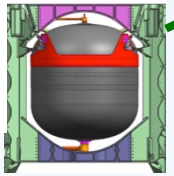
CPE Brassboard PPU





HIVHAC EDU2

Lt Wt propellant tank

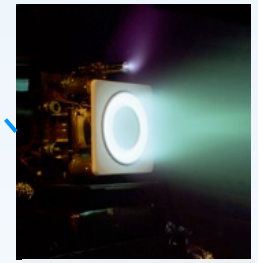


VACCO XFCM





Gimbal



BPT-4000 HV

- The HIVHAC EDU thruster offers improved performance and mission benefits over SOA
- The HIVHAC project has leveraged OCT SBIR funding to advance the HIVHAC thruster system readiness
- A flight-qualified VACCO XFCM was delivered to NASA GRC in March 2012 and will be integrated with the HIVHAC thruster

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

Ultra Lightweight Tank Technology (ULTT) for future planetary missions

Objective:

- To design ultra-lightweight propellant and pressurant tanks sized for MSL/MSR Skycrane with an option to manufacture and qualify.
- Goal: Achieve highest mass saving with reliability

Description

- This effort aims to develop the Composite Overwrapped Pressure Vessel (COPV) tanks for propellants and pressurants for Mars Sample Return (MSR) mission
- Tanks are most often the heaviest component on a spacecraft
- Currently component technologies are maturing and ready to be "harvested"

Benefits

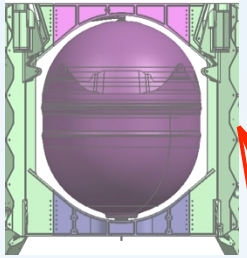
- **23** kg mass savings are achievable for 3 tanks sized for the Skycrane **(48% mass reduction)**
 - Mass savings can be passed on to the scientific payload or increase mass margin
- Broad impact to virtually ALL space missions as most use liquid propellants or pressurant
 - Europa Explorer tank mass can be reduced by 60 kg

Baseline Approach

- To complete CDR design package (June 2013)
- Option: Build and test three (3) Skycrane size tanks
- Option: Ready the tanks for flight demonstration in 2019 or beyond

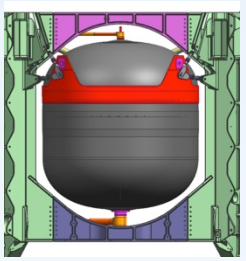
Descent Stage Propellant Tanks

Existing MSL Titanium Tank

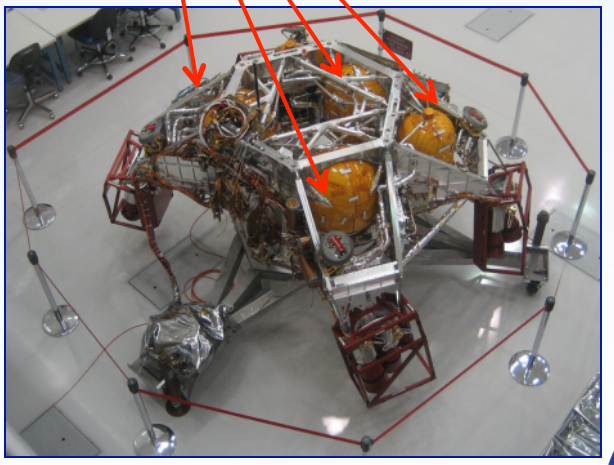


594mm Diameter, ~720mm Tall

Drop in replacement ultralight tank

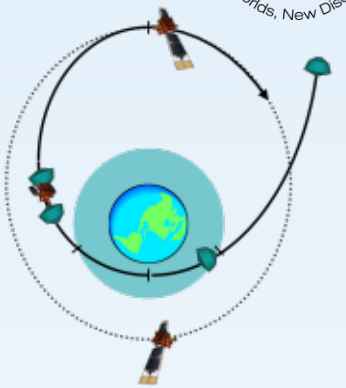


594mm Diameter, 684mm Tall



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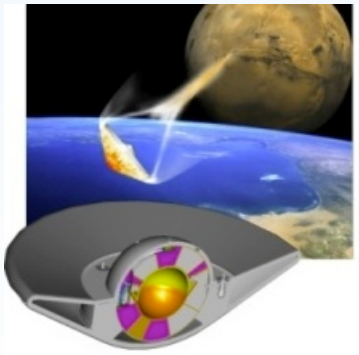
Entry Vehicle Technologies (EVT)



EVT Objectives

- Fully develop the tradespace and advanced system engineering methods in support of the Multi-Mission Earth Entry Vehicle (MMEEV) design
- Define technology needs/benefits within the context of the Planetary Science Decadal Survey
- Facilitate the infusion of ISPT's entry system products to robotic science missions
 - Aerocapture, TPS, aeroshell structures, MMEEVs, modeling and tools





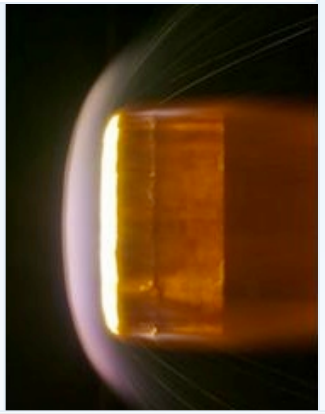
DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

Space Environmental Effects (SEE) Arc-jet Testing

- ***Objective: Investigate the effects of severe space environment exposure on candidate TPS materials***
- Materials selected (those previously matured):
 - Ablative TPS: Phencarb, SRAM, SLA-561V
 - Non-ablative TPS: Carbon-Carbon
 - Forebody and backshell applications
- Effects tested
 - Cold soak
 - Ionizing radiation
 - Hypervelocity (MMOD) impact
 - Followed by simulated entry conditions in ARC's AHF and IHF

- Preliminary results indicate that ablators are robust to combinations of severe space environments



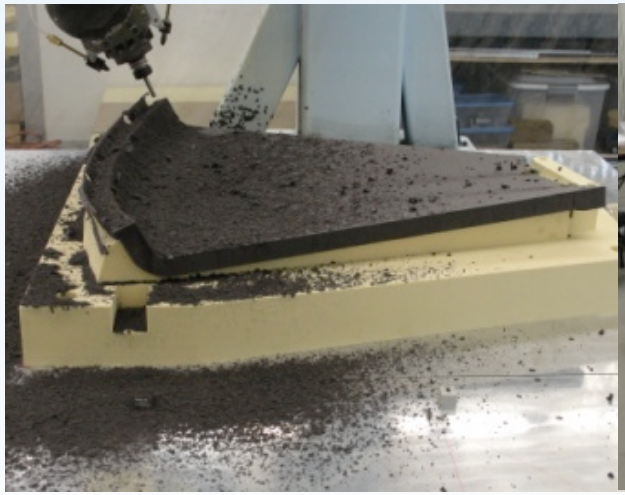




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2.65m Manufacturing Demonstration Unit (MDU) Aeroshell

- ***Objective: Validate modular honeycomb-reinforced ablator and high-temperature aeroshell structure design (400˚C bondline) manufacturing techniques in a Manufacturing Demonstration Unit (MDU)***
 - Modular TPS approach required for aeroshells >5m
 - Final surface machined, plans for CT scanning in FY-13
 - Scanning at Lawrence Livermore National Laboratories in FY13
 - Will show bondline, other defects; any density anomalies



Machining flank module



Packing module gaps



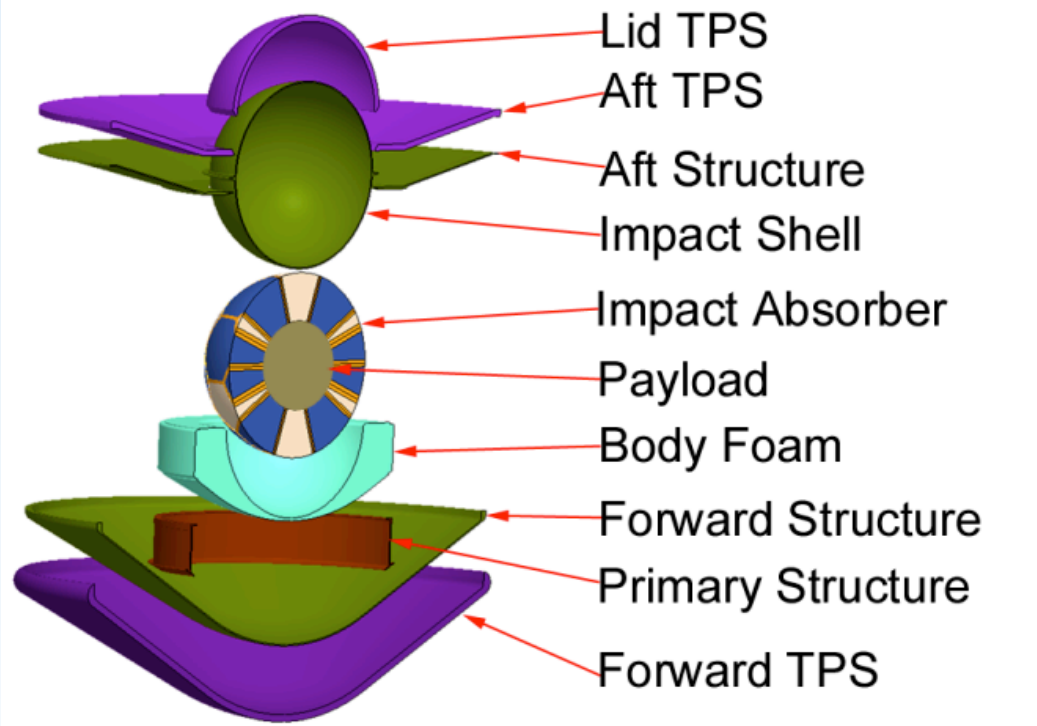
Final Aeroshell surface

TPS work performed by Applied Research Associates' Ablatives Laboratory

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

Multi-Mission Earth Entry Vehicle (MMEEV) Concept

- Passive, Single-Stage EDL method to minimize cost and risk
- Eliminates limited-reliability systems
- Well-suited for Mars Sample Return (MSR) and other sample return missions
- Detailed model available in the M-SAPE tool (see next slide)



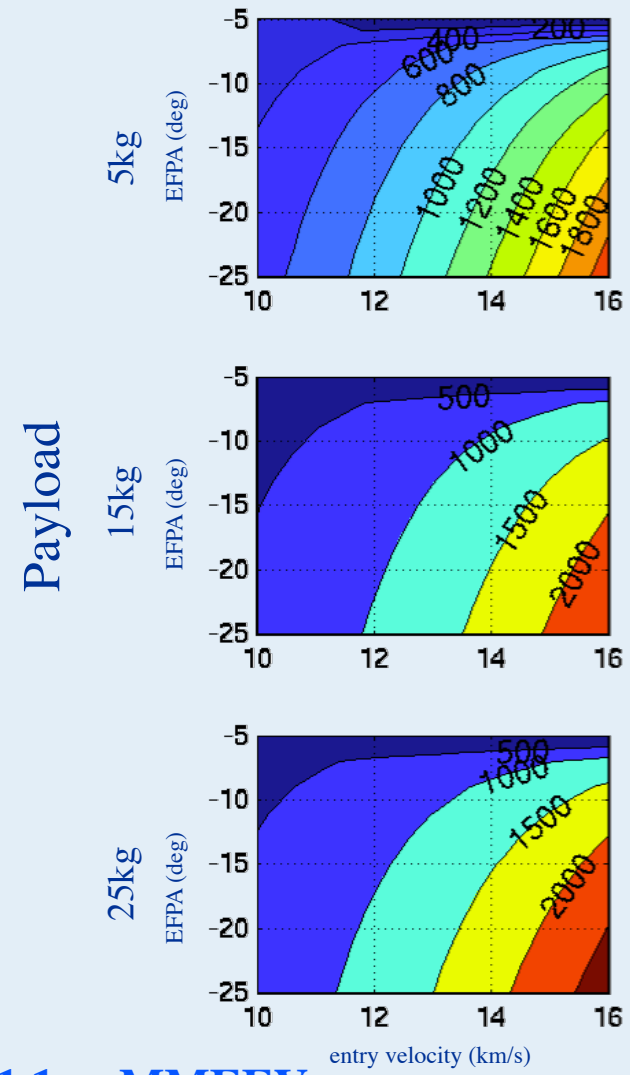
MMEEV Parametric Variable	Range
Payload	5 to 30 kg
Vehicle Diameter	0.5 to 2.5 m
Inertial Entry Velocity	10 to 16 km/s
Inertial Entry Flight Path Angle	-5° to -25°

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

M-SAPE Enhancements

- ***Objective: Develop models to significantly improve the analysis fidelity of the Multi-mission System Analysis for Planetary Entry (M-SAPE) tool***
 - M-SAPE integrates all EDL SE disciplines (aerodynamics, trajectory, structures, etc…)
 - Provides visualization of design trade space and vehicle optimization
- Models developed:
 - Thermal soak
 - TPS Mass Estimation Relationships
 - Impact sphere finite element
- Models have been developed and incorporated into M-SAPE

SAPE tool is already available for distribution through the LaRC software release process

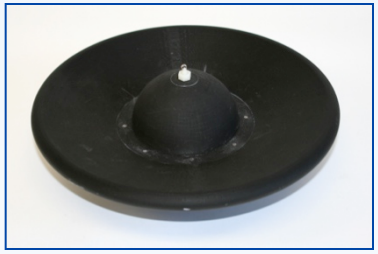


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EVT Plans

- Document and release M-SAPE
 - Publish an on-line database with access for approved users
 - ~10k cases with variations of payload mass & density, EFPA, TPS type, etc
 - Provide limited on-line access for additional cases
- CT scan 2.65 m Aeroshell, providing modular assembly technique validation
- Analyze and document Space Environmental Effects Testing results
- Archive and fully document prior Aerocapture work
- Complete MMEEV Vertical Spin Tunnel testing →
 - ***Objective: Provide significantly improved MMEEV trade space coverage for vehicle centerline length divided by diameter, CG, and inertias***
- Perform an entry vehicle Uranus Mission Study
- Support Woven TPS development plans

1.2m baseline



1.2m with back shell extender



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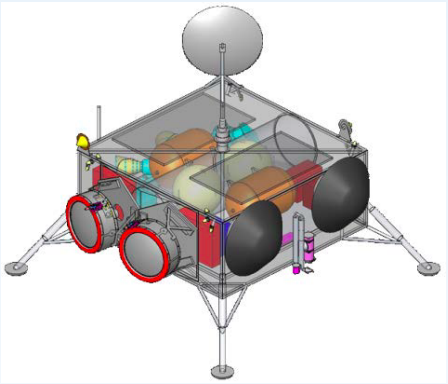
ISPT Systems Analysis

Systems Analysis Objective #1:

1) Conduct systems and mission studies to prioritize and guide investments and quantify mission benefit of ISPT products.

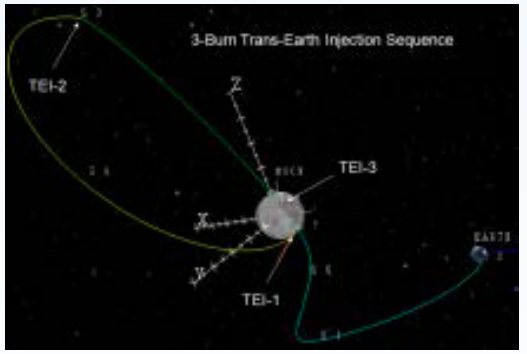
Mission / system design studies define technology requirements

- Critical to quantify mission benefits before hardware investment
- Mission design for NEXT requirements
- Refocus Study led to NEXT throttle table extension
- Refocus Study led to HIVHAC power range, life requirement
- Decadal study support quantified science benefit for SEP, REP, and AMBR engine technology



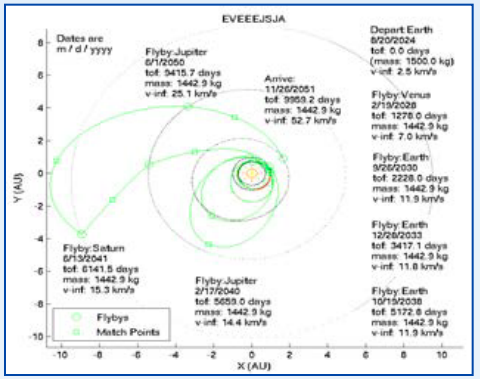
Recent Studies:

- Barbara SR, Ceres SR, Mars Moons' SR, NEARER, Discovery Cost Viability
- Supported 1/2 of all decadal studies: Uranus, Neptune, Chiron, Trojans, Vesta and Hebe, and Mercury
 - ISPT products used as baseline for every mission!



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ISPT Mission Design Tools

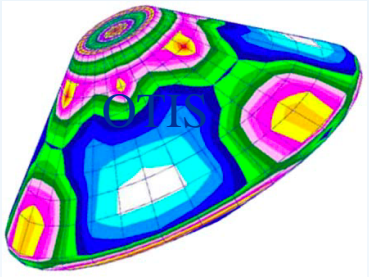


Systems Analysis Objective #2:

2) ***Develop tools for the user community to assist in ISPT product infusion.***
 - Low Thrust Trajectory Tool (LTTT) suite
 - Aerocapture Quicklook Tool (a.k.a. SAPE)
 - Advanced Chemical Propulsion System (ACPS) tool

In order to infuse new technologies, users must be able to assess the payoff.

- Sponsored development of Mystic, MALTO, Copernicus, and OTIS
- Initiated because results could not be independently validated
- Held tools training courses: MALTO in 2008, Copernicus in 2009, training as needed (most recent 2011)
- Aerocapture Quicklook Tool Released in 2010



Tool Success:

- Agency point-of-contact for trajectory analyses (e.g. HILTOP Validation)
- Provided tool training for MALTO, OTIS, and Copernicus
 - 100s from all NASA centers, academia and industry
 - Copernicus baseline tool for exploration (Constellation)
 - OTIS (GRC Led) NASA Software of the year
- Mystic used for Dawn mission operations, and tools used in Discovery proposals



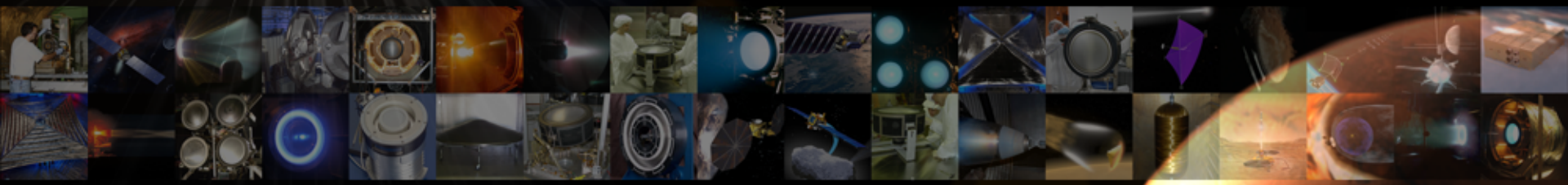
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Conclusion: ISPT Working Towards Technology Infusion

- ISPT is maturing technologies to be proposal/flight-ready
 - Development:
 - Hall Propulsion System for low-cost Discovery missions
 - Ultra-light weight propellant tank design as a drop-in replacement for Skycrane on a future Mars mission.
 - Proposals:
 - Technology infusion incentives were offered under the recent Discovery and New Frontiers AO's for NEXT, AMBR, and Aerocapture
 - Supporting use of ISPT developed technologies on proposals to OCT BAA's (AMBR, Solar Sails, Balance Flow Meter, and ultra-light weight propellant tank)
 - Flight:
 - Mars Science Laboratory (MSL) using ISPT developed HEAT sensors as part of the MSL Entry, Descent, and Landing Instrumentation (MEDLI) package
 - Fabricating 2 flight qualified AXFS. Interest (commercial, too) has increased due to pursuing the flight qualification step!

ISPT has several technologies which are ready for infusion
ISPT has several more technologies which will be ready tech infusion in the next several years

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Questions?

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